Quality of Service Parameters Optimization in Multi User Ultra Wideband Systems

Shangbo Wang*1, Joerg Huettner#2, Andreas Waadt*3, Andreas Ziroff#4, Peter Jung*5

*Department of Communication Technologies, Universität Duisburg-Essen, Duisburg 47048, Germany

#CT T DE HW1, Siemens Cooperate Technology, Otto-Hahn-Ring 6, Munich, Germany

1shangbo.wang@kommunikationstechnik.org; 2joerg.huettner@siemens.com;

3andreas.waadt@kommunikationstechnik.org; 4andreas.ziroff@siemens.com;

5peter.jung@kommunikationstechnik.org

Abstract- **Ultra-Wideband (UWB) networks are expected to support a wide range of communication-intensive, real-time multimedia applications. One of the key issues in UWB networks is optimization of Quality of Service (QoS) parameters. To meet the QoS demands of each UWB user and maximize the overall network throughput, several technical aspects shall be concerned, e.g. physical layer transmission format, multi user access format and routing solution. In this paper, a centralized Impulses Radio Ultra-wideband (IR-UWB) multi user system which contains one Network Coordinator (NC) is considered. A Successive Maximum Likelihood (SML) receiver is designed and presented. It shows that the novel ML receiver outperforms the rake receiver under the multipath environment. To improve the reception performance, robust UWB channel estimators which can adapt to the low Signal to Noise Raito (SNR) environment and the stochastic channel characteristics are investigated and deployed. Meanwhile, an Optimal Power Allocation (OPA) under the multi user environment is investigated and compared to Maximum Power Allocation (MPA) mechanisms. Our results show that the OPA can increase the overall network throughput in comparison with MPA.**

Keywords- Quality of Service (QoS); Ultra-wideband (UWB); Successive Maximum Likelihood (SML); Optimal Power Allocator (OPA); Maximum Power Allocation (MPA)

I. INTRODUCTION

In recent years, UWB network became a hot research issue since UWB has several advantages compared to narrowband communication systems. They are [5]:

- High Data Rates,
- Low Power Consumption,
- Interference Immunity,
- High Security,
- Reasonable Range,
- Low Complexity and Low Cost.

UWB distinguishes two different modulation schemes: Low Data Rate (LDR) UWB uses a pulse based modulation and is mainly used for low power, low cost applications, such as sensor networks. High Data Rate (HDR) UWB uses Orthogonal Frequency Division Modulation (OFDM) and is designed for applications with high data rate, such as multimedia communications [1].

In this research, we focus on LDR UWB network in which each UWB node uses Time Hopping – Pulse Position Modulation (TH-PPM) as its physical layer transmission format. Time Hopping Multiple Access (THMA) is selected in this research as the multi user access format with which different TH codes are allocated to different UWB users and each UWB user is exploiting orthogonality of different TH code to reduce the Multi User Interference (MUI) at the receiver [1]. Due to this characteristic, each UWB user is not required to be synchronized with Network Coordinator (NC) before it can start the data transmission.

However, in the asynchronous transmission mode, each user n may transmit its own data frame with its own relative time offset δ_n [1]. In addition, each transmission signal is subjected to multipath effect of UWB channel. Hence, MUI cannot be completely eliminated at the receiver. Therefore, transmission power of each UWB user is considered as the essential factor to influence the overall throughput of the UWB network.

Without optimal power allocation in the UWB network, each user prefers to use the maximum transmission power according to FCC limit to enhance its link quality (MPA). However, maximum transmission power of each user will lead to high energy consumption and high MUI to other users and then degrade the QoS of the UWB network.

In this research, we design an Optimal Power Allocator (OPA) which demonstrates a better performance than MPA. The NC is responsible to allocate each active UWB user a TH code and estimate the Channel State Information (CSI) and path loss parameters. Then OPA module applied on the NC shall be executed to allocate optimal transmission power to each UWB user according to these parameters.

To resist the multipath effect of the UWB channel and enhance the QoS of the UWB network, rake receiver and Successive Maximum Likelihood (SML) are deployed at the NC. The performances of the receivers are evaluated and compared.

The paper is outlined as follows: the system model for the considered impulse radio transmission scheme and the network structure are described in Section II; the structure of the rake receiver and SML is derived analytically in Section III; the Section IV mainly introduces the novel channel estimator based on IR-UWB systems; the structure and algorithm of OPA module are described analytically in Section V; the Bit Error Ratio (BER) at the receiver and the QoS under the multi user environment are depicted in Section VI; and the paper concludes with an overview of the results in Section VII.

II. SYSTEM MODEL AND NETWORK STRUCTURE

We begin with a description of the centralized UWB network structure. An UWB network with a set of N nodes is considered. For simplicity, it assumes that the UWB network contains only one location fixed NC, serving as the

administration node for the N UWB nodes. The N UWB nodes are uniformly distributed over the location area F. Figure 1 shows the centralized UWB network structure.

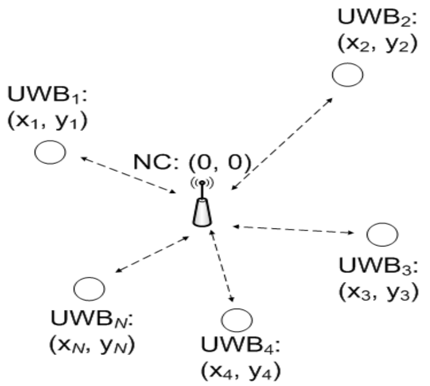

Fig. 1 Centralized UWB network structure

The Network Coordinator (NC) is fixed at (0, 0), while the N UWB nodes move over time and their locations are uniformly distributed over F. The demands for communication are always from the UWB users to the NC. In this paper, only the uplink transmission is considered. As multiple access schemes a pseudo random time hopping code is allocated to each active UWB user to lower the probability of repeated pulse collision from two users. Binary pulse position modulation (2-PPM) is assumed as modulation scheme for all UWB users. The transmitted signal of the user n can then be written as

$$s_n(t) = A_n \sum_{k=-\infty}^{+\infty} \sum_{j=1}^{N_s} g\left(t - kT_s - jT_f - c_{j,n}T_c - a_{k,n}\varepsilon - \delta_n\right) \tag{1}$$

$$n = 1, 2, ..., N$$

Where A_n is the amplitude of the transmitted pulse, $g(t)$ is the normalized transmitted pulse which adheres to the specification 802.15.4a [4], T_s is the symbol duration, T_f is the pulse repetition time interval, T_c is the chip duration, $a_{k,n}$ is the k-th information bit of the n-th user, ε is the pulse position modulation (PPM) offset and N_s is the number of pulse repetition period. It can be seen from equation, each information bit is transmitted by N_s identical pulses to enhance quality of reception and n-th user starts its transmission with the time offset δ_n, which is assumed to be uniformly distributed over the time [0 T_s].

III. STRUCTURE OF MULTI USER RAKE RECEIVER AND SUCCESSIVE MAXIMUM LIKELIHOOD RECEIVER

Each user n transmits its modulated UWB signal through a multipath channel $h_n(\tau,t)$ with channel impulse response [2]

$$\underline{h}_n(\tau,t) = \sum_{l=1}^{L} \underline{h}_{l,n}(t)\Delta\left(\tau - \tau_{l,n}(t)\right)$$

$$= \sum_{l=1}^{L} a_l(t) e^{i\theta_l(t)} \Delta\left(\tau - \tau_{l,n}(t)\right), \quad n = 1, 2, ..., N \tag{2}$$

In equation, Δ is the Dirac delta function. We assume that amplitude $a_l(t)$ and the phase $\theta_l(t)$ of each tap keep unchanged during each frame transmission due to the weak Doppler Effect in the indoor environment [2]. The equation can be rewritten as

$$\underline{h}_n(\tau) = \sum_{l=1}^{L} \underline{h}_{l,n}\Delta\left(\tau - \tau_{l,n}\right), n = 1, 2, ..., N, \tag{3}$$

where L is the number of paths of $h_n(\tau)$, $a_{l,n}$, $\theta_{l,n}$ and $\tau_{l,n}$ are amplitude, phase and the delay of the l-th path, respectively.

Hence, the received signal for user n can be expressed as:

$$r_n(t) = s_n(t) \otimes \underline{h}_n(t)$$

$$= A_n \sum_{k=-\infty}^{+\infty} \sum_{j=1}^{N_s} \sum_{l=1}^{L} \underline{h}_{l,n} g\left(t - \tau_{l,n} - kT_s - jT_f - c_{j,n}T_c - a_{k,n}\varepsilon - \delta_n\right) \tag{4}$$

In equation, "⊗" represents Kronecker operation and $g(t)$ is the transmitted pulse. Hence, the combined received signal from N UWB users can be expressed as:

$$r(t) = \sum_{n=1}^{N} r_n(t) + n(t), \tag{5}$$

where $n(t)$ is the Additive White Gaussian Noise with Power Spectral Density(PSD) N_0

A. Multi User Rake Receiver

It assumes that perfect channel estimation can be achieved at the receiver. The user n uses $v_n(t)$ as its matched signal at the receiver, which can be expressed as [1]:

$$v_n(t) = \sum_{j=1}^{N_s} g\left(t - jT_f - c_{j,n}T_c\right) - \sum_{j=1}^{N_s} g\left(t - jT_f - c_{j,n}T_c - \varepsilon\right) \tag{6}$$

The M-finger multi user rake receiver uses $v_n(t)$ to correlate the combined received signal $r(t)$ [1]. It gets

$$z_{k,n} = \sum_{l=1}^{M} \int_{(k-1)T_s}^{kT_s} h_{l,n}^{*} r(t) v_n\left(t - \tau_{m,n}\right) dt, \tag{7}$$

where $h_{l,n}^{*}$ is the complex conjugate of $h_{l,n}$ and $z_{k,n}$ is the k-th correlation result of n-th user [1]. Then the information bit can be estimated through

$$\hat{a}_{k,n} = \begin{cases} 0 & \mathrm{Re}\left\{z_{k,n}\right\} > 0 \\ 1 & \mathrm{Re}\left\{z_{k,n}\right\} < 0 \end{cases}, n = 1, 2, ..., N \tag{8}$$

In equation, $z_{k,n}$ may be a complex number due to two reasons:

- the integral time length is T_s, which is smaller than the received symbol duration due to the time delay of multi path channel and;
- the number M of fingers may be smaller than the number L of channel paths.

It is obvious that $z_{k,n}$ may contain MUI due to the possible pulses overlap among the N users. We define that $\underline{I}_{mn}$ is the interference from m-th user to n-th user. Since each UWB user starts its transmission at arbitrary time point, each interferer m of n-th user transmits its frame with a relative time offset δ_m, which is uniformly distributed over the time [0 T_s]. The transmission power and path gain of each UWB user can be expressed as:

$$\boldsymbol{p}_{\mathrm{tx}} = \left[p_{1,\mathrm{tx}} \quad p_{2,\mathrm{tx}} \quad \cdots \quad p_{N,\mathrm{tx}} \right]^{\mathrm{T}} \tag{9}$$

and

$$\boldsymbol{g} = \left[g_1 \quad g_2 \quad \cdots \quad g_N \right]. \tag{10}$$

Hence, $\underline{I}_{mn}$ can be calculated as:

$$\underline{I}_{mn} = \frac{1}{T_s} \int_0^{T_s} \left[\left(\int_0^{T_s} \sum_{l=1}^{M} \underline{h}^*_{l,n} r'_m (t-\delta) v_n (t - \tau_{l,n}) \, dt \right)^2 \right] d\delta, \tag{11}$$

where T_s is the number of symbol duration and

$$r'_m(t) = A_m \sum_{l=1}^{L} \left(\underline{h}_{l,m} \sum_{j=1}^{N_s} g\left(t - jT_f - c_{j,m} T_c - \tau_{l,m}\right) \right), \tag{12}$$

where A_m is the amplitude of the transmitted pulse of m-th user, which has

$$p_{m,\mathrm{tx}} = A_m^2 \tag{13}$$

due to the extreme short pulse duration. We set

$$\sigma_{mn}(\delta) = \int_0^{T_s} \left(\sum_{j=1}^{N_s} g\left(t - jT_f - c_{j,m} T_c - \delta\right) \right) v_n(t) \, dt, \tag{14}$$

where δ denotes the time offset. The equation can be approximated as

$$\begin{aligned} \underline{I}_{mn} &\approx \left(\frac{A_m}{T_s} \sum_{l=1}^{M} \left(h^*_{l,n} h_{l,m} \right) \int_0^{T_s} \sigma_{mn}(\delta) \, d\delta \right)^2 \\ &= \frac{p_{m,\mathrm{tx}}}{T_s^2} \left(\sum_{l=1}^{M} \left(h^*_{l,n} h_{l,m} \right) \right)^2 \left(\int_0^{T_s} \sigma_{mn}(\delta) \, d\delta \right)^2 \end{aligned} \tag{15}$$

For n-th user, the sum of interference can be expressed as:

$$\underline{I}_n = \sum_{m=1, m \neq n}^{N} \underline{I}_{mn}, \; n = 1, 2, \ldots, N \tag{16}$$

According to Cauchy–Schwarz inequality,

$$\underline{I}_{mn} \leq \frac{1}{T_s} \int_0^{T_s} \left[\left(\int_0^{T_s} \left(r'_m (t-\delta) \right)^2 dt \right) \left(\int_0^{T_s} \left(\sum_{l=1}^{M} \underline{h}^*_{l,n} v_n \left(t - \tau_{l,n}\right) \right)^2 dt \right) \right] d\delta \tag{17}$$

Since the monocycles appearing in $s_n(t)$ are widely separated from each other, even a small time misalignment makes virtually orthogonal. The equation can be written as:

$$\begin{aligned} \underline{I}_{mn} &\leq \frac{1}{T_s} \int_0^{T_s} \left[\left(|A_m|^2 \sum_{l=1}^{L} N_s \left|\underline{h}_{l,m}\right|^2 \right) \left(2 \sum_{l=1}^{M} N_s \left|\underline{h}^*_{l,n}\right|^2 \right) \right] d\delta \\ &= \frac{2 p_{m,\mathrm{tx}} N_s^2}{T_s} \int_0^{T_s} \left(\sum_{l=1}^{L} \left|\underline{h}_{l,m}\right|^2 \sum_{l=1}^{M} \left|\underline{h}^*_{l,n}\right|^2 \right) d\delta \\ &= 2 p_{m,\mathrm{tx}} N_s^2 \sum_{l=1}^{L} \left|\underline{h}_{l,m}\right|^2 \sum_{l=1}^{M} \left|\underline{h}^*_{l,n}\right|^2 \end{aligned} \tag{18}$$

The useful signal energy E_b can be expressed as:

$$E_{b,n} = \left(\int_0^{T_s} \sum_{l=1}^{M} \underline{h}^*_{l,n} r'_n(t) v_n \left(t - \tau_{l,n}\right) dt \right)^2, \tag{19}$$

where

$$r'_n(t) = A_n \sum_{l=1}^{L} \left(\underline{h}_{l,n} \sum_{j=1}^{N_s} g\left(t - jT_f - c_{j,n} T_c - \tau_{l,n}\right) \right). \tag{20}$$

The equation can be expressed as:

$$\begin{aligned} E_{b,n} &= \left(\int_0^{T_s} \sum_{l_{tx}=1}^{M} \underline{h}^*_{l_{tx},n} A_n \sum_{l_{rx}=1}^{L} \underline{h}_{l_{rx},n} \sum_{j=1}^{N_s} g\left(t - jT_f - c_{j,n} T_c - \tau_{l_{rx},n}\right) v_n \left(t - \tau_{l_{tx},n}\right) dt \right)^2 \\ &\approx \left(A_n N_s \sum_{l=1}^{M} \left|\underline{h}_{l,n}\right|^2 \right)^2 = p_{n,\mathrm{tx}} N_s^2 \left(\sum_{l=1}^{M} \left|\underline{h}_{l,n}\right|^2 \right)^2 \end{aligned} \tag{21}$$

Hence, the Signal to Interference and Noise Ratio (SINR) at the receiver for user n can be written as:

$$\gamma_n = \frac{E_{b,n}}{N'_0 + I_n}, \; n = 1, 2, \ldots, N, \tag{22}$$

where I_n is from equation and considered as the Additive White Gaussian Noise (AWGN) at the receiver and $N'_0 = N_s N_0$ [1]. Hence, the Bit Error Rate (BER) of the Multi User Rake Receiver can be expressed as [1]

$$P_{b,n} = \frac{1}{2} \mathrm{erfc}\left(\sqrt{\frac{\gamma_n}{2}} \right). \tag{23}$$

B. *Successive Maximum Likelihood Receiver*

It assumes that the perfect channel estimation of each user can be achieved. The discrete complex channel impulse response of n-th user is:

$$\underline{\boldsymbol{h}}_n = \left[\underline{h}_{1,n} \quad \underline{h}_{2,n} \quad \cdots \quad \underline{h}_{W_n,n} \right], \tag{24}$$

where W_n is number of paths for the n-th user, whose energy is larger than 85% of the whole channel energy. The sampling rate is $2/T_c$ and we set

$$T_c = \delta + T_p, \tag{25}$$

where T_p is the pulse duration and $\delta = T_p$. The format of transmitted frame of n-th user can be illustrated as in Figure 2:

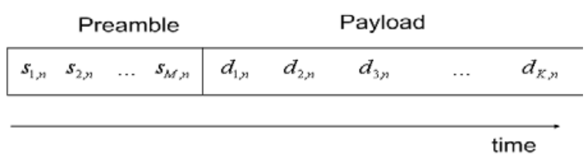

Fig. 2 Structure of transmitted frame

Figure 2 shows the frame structure of each UWB user. Each transmitted frame consists of two parts: preamble and payload. The preambles are known by the receiver while the information bits are contained in the payload. Before transmission, each user shall be allocated a different preamble sequence $\boldsymbol{s_n}$ by the NC, which shall be spread by the delta function δ_L according to [4], which can be expressed as:

$$\delta_{L_p} = \underbrace{\left[1 \quad 0 \quad \cdots \quad 0 \right]}_{L_p}. \tag{26}$$

Hence, the spread preamble sequence can be expressed as

$$\begin{aligned} \boldsymbol{s}^s_n &= \left[s_{1,n} \otimes \delta_{L_p} \quad s_{2,n} \otimes \delta_{L_p} \quad \cdots \quad s_{M,n} \otimes \delta_{L_p} \right] \\ &= \left[g_{1,n} \quad g_{2,n} \quad \cdots \quad g_{ML_p,n} \right] \end{aligned}. \tag{27}$$

"$\otimes$" is the Kronecker operation [4]. Each data symbol of the n-th user shall be spread by the Time Hopping code $\boldsymbol{c}_n$, which can be expressed as a vector with length of L_c [4]

$$\boldsymbol{c}_n = \underbrace{0 \quad 0 \quad 1 \quad \cdots \quad 0}_{1} \cdots \underbrace{0 \quad 1 \quad 0 \quad \cdots \quad 0}_{N_{\text{Burst}}}. \tag{28}$$

It can be seen from, the position of "1" in each burst can be determined by the value of the allocated Time Hopping code. The k-th transmitted bits of n-th user shall be modulated through c_n and the time offset vector $\boldsymbol{\sigma_i}$ [1].

$$\sigma_k = \begin{cases} \begin{bmatrix} 1 & 0 \end{bmatrix}, \ d_{k,n} = 0 \\ \begin{bmatrix} 0 & 1 \end{bmatrix}, \ d_{k,n} = 1 \end{cases} \tag{29}$$

The k-th spread transmitted bits of the n-th user can be expressed as a vector with the length of $2L_\text{c}$

$$\boldsymbol{d}^\text{s}_{k,n} = A_n \boldsymbol{c}_n \otimes \sigma_k, \tag{30}$$

where A_n is the amplitude of transmitted pulse. For each transmitted bit k, we set the discrete complex channel of the n-th user in a Toeplitz matrix form $\underline{\boldsymbol{H}}_{k,n}$

$$\underline{\boldsymbol{H}}_{k,n} = \underbrace{\begin{bmatrix} \underline{h}_{1,n} & 0 & \cdots & 0 \\ \underline{h}_{2,n} & \underline{h}_{1,n} & \cdots & 0 \\ \vdots & \underline{h}_{2,n} & \cdots & 0 \\ \underline{h}_{W_n,n} & \vdots & \cdots & 0 \\ 0 & \underline{h}_{W_n,n} & \ddots & \underline{h}_{1,n} \\ 0 & 0 & \ddots & \underline{h}_{2,n} \\ 0 & 0 & \cdots & \vdots \\ 0 & 0 & \cdots & \underline{h}_{W_n,n} \end{bmatrix}}_{2L_\text{c}}, \tag{31}$$

which has (W_n+$2L_\text{c}$-1) rows and $2L_\text{c}$ columns. The original k-th received data vector of the n-th user with the length of (W_n+$2L_\text{c}$-1) can be expressed as:

$$\underline{\boldsymbol{r}}_{k,n} = \underline{\boldsymbol{H}}_{k,n} \boldsymbol{d}^\text{s}_{k,n} + \underline{\boldsymbol{n}}_{k,n}, k = 1, 2, ..., K. n = 1, 2, ..., N. \tag{32}$$

We set

$$L_\text{r} = W_n + 2L_\text{c} - 1. \tag{33}$$

Then we can get

$$K_\text{ISI} = \left\lceil \frac{L_\text{r}}{2L_\text{c}} \right\rceil - 1, \tag{34}$$

which is the number of data symbols that are subjected to the Inter Symbol Interference (ISI) from the current symbol k due to the multipath effect. The $\underline{\boldsymbol{H}}_{k,n}$ can be rewritten as:

$$\underline{\boldsymbol{H}}_{k,n} = \begin{bmatrix} \underline{\boldsymbol{H}}^{(1)}_{k,n} \\ \underline{\boldsymbol{H}}^{(2)}_{k,n} \\ \vdots \\ \underline{\boldsymbol{H}}^{(1+K_\text{ISI})}_{k,n} \end{bmatrix}, \tag{35}$$

where each sub matrix $\underline{\boldsymbol{H}}^{(i)}_{k,n}, i = 1, 2, ..., K_\text{ISI}$ has $2L_\text{c}$ rows and $2L_\text{c}$ columns, while $\underline{\boldsymbol{H}}^{(1+K_\text{ISI})}_{k,n}$ has (L_r-$2K_\text{ISI}L_\text{c}$) rows and $2L_\text{c}$ columns. The received data vector of n-th user can be written as:

$$\underline{\boldsymbol{r}}_n = \begin{bmatrix} \underline{\boldsymbol{r}}^{(1)}_n \\ \underline{\boldsymbol{r}}^{(2)}_n \\ \vdots \\ \underline{\boldsymbol{r}}^{(K)}_n \end{bmatrix} = \underline{\boldsymbol{H}}_n \begin{bmatrix} \boldsymbol{d}^\text{s}_{1,n} \\ \boldsymbol{d}^\text{s}_{2,n} \\ \vdots \\ \boldsymbol{d}^\text{s}_{K,n} \end{bmatrix} + \underline{\boldsymbol{n}}_n, \tag{36}$$

where

$$\underline{\boldsymbol{H}}_n = \underbrace{\begin{bmatrix} \underline{h}_{1,n} & 0 & \cdots & 0 \\ \underline{h}_{2,n} & \underline{h}_{1,n} & \cdots & 0 \\ \vdots & \underline{h}_{2,n} & \cdots & 0 \\ \underline{h}_{W_n,n} & \vdots & \cdots & 0 \\ 0 & \underline{h}_{W_n,n} & \ddots & \underline{h}_{1,n} \\ 0 & 0 & \ddots & \underline{h}_{2,n} \\ 0 & 0 & \cdots & \vdots \\ 0 & 0 & \cdots & \underline{h}_{W_n,n} \end{bmatrix}}_{2KL_\text{c}}. \tag{37}$$

The observed data vector at the receiver can be expressed as:

$$\underline{\boldsymbol{r}} = \sum_{n=1}^{N} \underline{\boldsymbol{r}}_n = \begin{bmatrix} \underline{\boldsymbol{r}}^{(1)} \\ \underline{\boldsymbol{r}}^{(2)} \\ \vdots \\ \underline{\boldsymbol{r}}^{(K)} \end{bmatrix}. \tag{38}$$

We get

$$\begin{aligned} \boldsymbol{d}^{\text{s},0}_{k,n} &= A_n \underline{c}_n \otimes \begin{bmatrix} 1 & 0 \end{bmatrix}, \\ \boldsymbol{d}^{\text{s},1}_{k,n} &= A_n \underline{c}_n \otimes \begin{bmatrix} 0 & 1 \end{bmatrix}, \\ \underline{\boldsymbol{z}}^{0}_{k,n} &= \underline{\boldsymbol{H}}^{(1)}_{k,n} \boldsymbol{d}^{\text{s},0}_{k,n} + \sum_{i=1}^{K_\text{ISI}} \underline{\boldsymbol{H}}^{(i+1)}_{k-i,n} \hat{\boldsymbol{d}}^{\text{s}}_{k-i,n}, \\ \underline{\boldsymbol{z}}^{1}_{k,n} &= \underline{\boldsymbol{H}}^{(1)}_{k,n} \boldsymbol{d}^{\text{s},1}_{k,n} + \sum_{i=1}^{K_\text{ISI}} \underline{\boldsymbol{H}}^{(i+1)}_{k-i,n} \hat{\boldsymbol{d}}^{\text{s}}_{k-i,n}, \\ \hat{d}_{k,n} &= \arg\min_{m} \left(\left\| \underline{\boldsymbol{z}}^{m}_{k,n} - \underline{\boldsymbol{r}}^{(k)} \right\| \right), m = 0, 1. \end{aligned} \tag{39}$$

IV. CHANNEL ESTIMATION

Multi-tap channel shall be estimated to compensate the convolution effect of channel. This section mainly introduces two different approaches: Data Aided (DA) and Non-data Aided (NDA), where the former exploits the transmitted preamble and the latter exploit only the characteristics of the modulation format.

A. Maximum Likelihood (ML) Channel Estimator

The received base band signal can be written as:

$$r_n(t) = \sum_{l=1}^{L} \underline{h}_{l,n} s_n\left(t - \tau_{l,n}\right) + n_n(t), n = 1, 2, ..., N. \tag{40}$$

If we use $\tilde{x}$ to indicate a trial value of a variable x, then we define

$$\tilde{s}_n(t) = \sum_{l=1}^{L} \underline{h}_{l,n} s_n\left(t - \tau_{l,n}\right), n = 1, 2, ..., N. \tag{41}$$

Hence, the conditional probability density functions of $r_n(t)$ can be written as:

$$\mathrm{p}(r_n(t)) = \frac{1}{\sqrt{2\pi\sigma}} \exp\left(-\frac{\left(r_n(t)-\tilde{s}_n(t)\right)^2}{2\sigma^2}\right). \quad (42)$$

According to Maximum Likelihood (ML) criteria, it can get

$$\begin{aligned}\left(\hat{\underline{h}}_{l,n} \quad \hat{\underline{\tau}}_{l,n}\right) &= \underset{\left(\hat{\underline{h}}_{l,n},\hat{\underline{\tau}}_{l,n}\right)}{\arg\max}\left(\mathrm{p}\left(r_n(t)\right)\right) \\ &= \underset{\left(\hat{\underline{h}}_{l,n},\hat{\underline{\tau}}_{l,n}\right)}{\arg\min}\left(\int_0^{T_{\mathrm{pre}}}\left|\left(r_n(t)-\tilde{s}_n(t)\right)\right|^2 \mathrm{dt}\right)\end{aligned} \quad (43)$$

Where T_{pre} is the preamble duration. Since $r_n(t)^2$ is fixed, it can be rewritten as

$$\left(\hat{\underline{h}}_{l,n} \quad \hat{\underline{\tau}}_{l,n}\right) = \underset{\left(\hat{\underline{h}}_{l,n},\hat{\underline{\tau}}_{l,n}\right)}{\arg\max}\left(\int_0^{T_{\mathrm{pre}}}\left(2r_n(t)\tilde{s}_n(t)-\tilde{s}_n(t)\right)^2 \mathrm{dt}\right) \quad (44)$$

$$\left(\hat{\underline{h}}_{l,n} \quad \hat{\underline{\tau}}_{l,n}\right) \approx \underset{\left(\hat{\underline{h}}_{l,n},\hat{\underline{\tau}}_{l,n}\right)}{\arg\max}\left(\int_0^{T_{\mathrm{pre}}} 2r_n(t)\sum_{l=1}^{W_n}\underline{h}_{l,n}s_n\left(t-\tau_{l,n}\right)\mathrm{dt}\text{-}\sum_{l=1}^{W_n}\left\|\underline{h}_{l,n}\right\|^2 E_{\mathrm{s}}\right) \quad (45)$$

where E_{s} is the energy of $s(t-\tau_l)$ and

$$\int_0^{T_{\mathrm{pre}}}\underline{h}_{l_1,n}\underline{h}_{l_2,n}s\left(t-\tau_{l_1,n}\right)s\left(t-\tau_{l_2,n}\right)\mathrm{dt}\approx 0, l_1\neq l_2. \quad (46)$$

Due to the reality of first part of, $\underline{h}_{l,n}$ shall have an opposite phase to $\int_0^{T_{\mathrm{pre}}} r_n(t)s_n\left(t-\tau_{l,n}\right)\mathrm{dt}$. Hence, $\underline{h}_{l,n}$ can be rewritten as $\left|\underline{h}_{l,n}\right|\mathrm{e}^{-j\theta}$, where is the phase of $\int_0^{T_{\mathrm{pre}}} r_n(t)s_n\left(t-\tau_{l,n}\right)\mathrm{dt}$. We set

$$\Lambda\left(\underline{\boldsymbol{h}}_n, \boldsymbol{\tau}_n\right) = 2\sum_{l=1}^{W_n}\left|\underline{h}_{l,n}\right|e^{-j\theta}\int_0^{T_{\mathrm{pre}}} r_n(t)s\left(t-\tau_{l,n}\right)\mathrm{dt}\text{-}\sum_{l=1}^{W_n}\left\|\underline{h}_{l,n}\right\|^2 E_{\mathrm{s}} \quad (47)$$

To get maximum value of $\Lambda\left(\underline{\boldsymbol{h}}_n, \boldsymbol{\tau}_n\right)$, we set

$$\begin{cases}\dfrac{\partial\Lambda\left(\underline{\boldsymbol{h}}_n, \boldsymbol{\tau}_n\right)}{\left|\underline{h}_{1,n}\right|}=0\\ \dfrac{\partial\Lambda\left(\underline{\boldsymbol{h}}_n, \boldsymbol{\tau}_n\right)}{\left|\underline{h}_{2,n}\right|}=0\\ \vdots\\ \dfrac{\partial\Lambda\left(\underline{\boldsymbol{h}}_n, \boldsymbol{\tau}_n\right)}{\left|\underline{h}_{W_n,n}\right|}=0\end{cases}. \quad (48)$$

B. Blind Channel Estimation

We take

$$x_{k,n}(t) = A_n\sum_{j=1}^{N_{\mathrm{s}}} g\left(t-\tau_{l,n}-kT_{\mathrm{s}}-jT_{\mathrm{f}}-c_{j,n}T_{\mathrm{c}}-a_{k,n}\varepsilon-\delta_n\right) \quad (49)$$

According to, the k-th received data vector of n-th user can be expressed as

$$r_{k,n}(t) = \sum_{l=1}^{L}\underline{h}_{l,n}x_{k,n}\left(t-\tau_{l,n}\right)+n(t). \quad (50)$$

Let's first evaluate the expected value of $r_n(t)$ over the binary zero-or-one information symbols. Due to the equal probability of transmitted symbols '0' and '1', it can get

$$\begin{aligned} r_{\mathrm{a},n}(t) &= \frac{1}{K}\sum_{k=1}^{K} r_{k,n}(t) \\ &= \left(\frac{x_{k,n}(t)+x_{k,n}(t-\varepsilon)}{2}\right)\otimes h_n(t) \\ &= x_{\mathrm{a}}(t)\otimes h_n(t), n=1,2,...,N\end{aligned} \quad (51)$$

K is the number of transmitted symbols. Hence, the spectrum of estimated channel can be expressed as

$$h_n(f) = r_{\mathrm{a}}(f)./x_{\mathrm{a}}(f). \quad (52)$$

The data part of a transmitted frame can be expressed as:

$$\boldsymbol{d}_n = \left[d_{0,n} \quad d_{1,n} \quad \cdots \quad d_{L_{\mathrm{s},n}-1,n}\right], n=1,2,...,N, \quad (53)$$

where

$$L_{\mathrm{s},n} = 2KL_{\mathrm{c}}. \quad (54)$$

The received data can be expressed as:

$$\boldsymbol{r}_n = \left[r_{0,n} \quad r_{1,n} \quad \cdots \quad r_{L_{\mathrm{r},n}-1,n}\right]^{\mathrm{T}}, \quad (55)$$

where

$$L_{\mathrm{r},n} = L_{\mathrm{s},n} + W_n - 1. \quad (56)$$

It assumes that the number W_n of channel is known by the receiver. To estimate the channel impulse response, the transmitted data frame is separated into several data units of equal length $L_{\mathrm{sd},n}$, which can be expressed as

$$\begin{aligned} L_{\mathrm{sd},n} &= cL_{k,n} \\ c &= \left\lceil\frac{W_n}{L_{k,n}}\right\rceil, n=1,2,...,N\end{aligned}. \quad (57)$$

$\lceil\ \rceil$ denotes the next rounded up integer. We set

$$\begin{aligned} L_{\mathrm{sr},n} &= ML_{k,n} \\ M &= \left\lceil\frac{L_{\mathrm{sd},n}+W_n-1}{L_{k,n}}\right\rceil\end{aligned}. \quad (58)$$

Meanwhile, the received data frame is separated into I_n data units, where each sub data unit has the equal length of $L_{\mathrm{sr},n}$.

$$I_n = \left\lfloor\frac{L_{r,n}}{L_{\mathrm{sr},n}}\right\rfloor, n=1,2,...,N. \quad (59)$$

$\lfloor\ \rfloor$ represents the next rounded down integer. The average transmitted data can be expressed as:

$$d_{\mathrm{a},n} = \frac{1}{2}\left(d_{0,n} + d_{1,n}\right), n = 1, 2, ..., N, \tag{60}$$

where $d_{0,n}$ and $d_{1,n}$ are the 0 and 1 vector, respectively. It can be further expressed as:

$$d_{\mathrm{a},n} = \left[d^{\mathrm{a}}_{0,n} \quad d^{\mathrm{a}}_{1,n} \quad \cdots \quad d^{\mathrm{a}}_{L_{k,n}-1,n} \right], n = 1, 2, ..., N \tag{61}$$

We combine the c $d_{\mathrm{a},n}$ to an average transmitted sub data unit:

$$d^{\mathrm{s}}_{\mathrm{a},n} = \left[d^{\mathrm{a,s}}_{0,n} \quad d^{\mathrm{a,s}}_{1,n} \quad \cdots \quad d^{\mathrm{a,s}}_{cL_{k,n}-1,n} \right]. \tag{62}$$

The received data vector can be rewritten as:

$$\underline{\boldsymbol{r}}_n = \left[\underline{\boldsymbol{r}}^{(0)\mathrm{T}}_{\mathrm{s},n} \quad \underline{\boldsymbol{r}}^{(1)\mathrm{T}}_{\mathrm{s},n} \quad \cdots \quad \underline{\boldsymbol{r}}^{(I_n-1)\mathrm{T}}_{\mathrm{s},n} \right]^{\mathrm{T}}, n = 1, 2, ..., N \tag{63}$$

where $\underline{\boldsymbol{r}}^{(i)\mathrm{T}}_{\mathrm{s},n}, i = 0, 1, ..., I_n - 1$ is i-th received sub vector. To estimate the complex discrete channel, the received sub vector shall average over the duration of an entire data frame.

$$\underline{\boldsymbol{r}}_{\mathrm{a},n} = \frac{1}{I_n} \sum_{i=0}^{I_n-1} \underline{\boldsymbol{r}}^{(i)}_{\mathrm{s},n}, n = 1, 2, ..., N, \tag{64}$$

which has the length of $L_{\mathrm{sr},n}$. Then the transmitted data unit with the same length can be written as:

$$\boldsymbol{d}^{\mathrm{s},L}_{\mathrm{a},n} = \left[d^{\mathrm{a,s}}_{0,n} \quad d^{\mathrm{a,s}}_{1,n} \quad \cdots \quad d^{\mathrm{a,s}}_{L_{\mathrm{sr},n}-1,n} \right]. \tag{65}$$

With the matrices:

$$\boldsymbol{A}_{\mathrm{pos}} = \underbrace{\begin{bmatrix} \boldsymbol{0} \\ \boldsymbol{A}^{\mathrm{p}}_{\mathrm{pos}} \end{bmatrix}}_{W_n} \tag{66}$$

where

$$\boldsymbol{A}^{\mathrm{p}}_{\mathrm{pos}} = \underbrace{\begin{bmatrix} d^{\mathrm{a,s}}_{cL_{k,n},n} & 0 & \cdots & 0 \\ d^{\mathrm{a,s}}_{cL_{k,n}+1,n} & d^{\mathrm{a,s}}_{cL_{k,n},n} & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ d^{\mathrm{a,s}}_{L_{\mathrm{sr},n}-1,n} & d^{\mathrm{a,s}}_{L_{\mathrm{sr},n}-2,n} & \cdots & d^{\mathrm{a,s}}_{L_{\mathrm{sr},n}-W_n,n} \end{bmatrix}}_{W_n} \tag{67}$$

And

$$\boldsymbol{A}_{\mathrm{pre}} = \underbrace{\begin{bmatrix} \boldsymbol{A}^{\mathrm{p}}_{\mathrm{pre}} \\ \boldsymbol{0} \end{bmatrix}}_{W_n}, \tag{68}$$

where

$$\boldsymbol{A}^{\mathrm{p}}_{\mathrm{pre}} = \underbrace{\begin{bmatrix} 0 & d^{\mathrm{a,s}}_{L_{\mathrm{sr},n}-1,n} & \cdots & d^{\mathrm{a,s}}_{L_{\mathrm{sr},n}-W_n+1,n} \\ 0 & 0 & \cdots & d^{\mathrm{a,s}}_{L_{\mathrm{sr},n}-W_n+2,n} \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & d^{\mathrm{a,s}}_{L_{\mathrm{sr},n}-1,n} \end{bmatrix}}_{W_n} \tag{69}$$

Then the pure data vector of length $L_{\mathrm{sr},n}$ can be written as

$$\underline{\boldsymbol{r}}^{\mathrm{p}}_{\mathrm{a},n} = \underline{\boldsymbol{r}}_{\mathrm{a},n} - \boldsymbol{A}_{\mathrm{pos}} \underline{\boldsymbol{h}}_n - \boldsymbol{A}_{\mathrm{pre}} \underline{\boldsymbol{h}}_n. \tag{70}$$

With $L_{\mathrm{sr},n}$ point DFT matrix $\underline{\boldsymbol{G}}$, we have

$$\underline{\boldsymbol{r}}^{\mathrm{p,F}}_{\mathrm{a},n} = \underline{\boldsymbol{G}}\underline{\boldsymbol{r}}^{\mathrm{p}}_{\mathrm{a},n}, n = 1, 2, ..., N, \tag{71}$$

and

$$\underline{\boldsymbol{d}}^{\mathrm{s,F}}_{\mathrm{a},n} = \underline{\boldsymbol{G}} \left. \begin{bmatrix} \boldsymbol{d}^{\mathrm{s}}_{\mathrm{a},n} \\ \boldsymbol{0} \end{bmatrix} \right\} L_{\mathrm{sr},n}. \tag{72}$$

Then the spectrum of estimated channel impulse response can be expressed as

$$\hat{\underline{\boldsymbol{h}}}^{\mathrm{F}}_n = \underline{\boldsymbol{r}}^{\mathrm{p,F}}_{\mathrm{a},n} ./ \underline{\boldsymbol{d}}^{\mathrm{s,F}}_{\mathrm{a},n}, n = 1, 2, ..., N. \tag{73}$$

V. V. OPTIMAL POWER ALLOCATOR

In this paper, the Optimal Power Allocator (OPA) is only investigated with the multi user rake receiver. The bit error probability Pb,n can be calculated as

$$P_{\mathrm{b},n} = \frac{1}{2}\mathrm{erfc}\left(\sqrt{\frac{1}{2}\left(\frac{p_{n,\mathrm{tx}} N_{\mathrm{s}}^2 \left(\sum_{l=1}^{M} \left| \underline{h}_{l,n} \right|^2 \right)^2}{N_{\mathrm{s}} N_0 + \sum_{m=1, m\neq n}^{N} \frac{p_{m,\mathrm{tx}}}{T_{\mathrm{s}}^2} \left(\sum_{l=1}^{M} \left(h^*_{l,n} h_{l,m} \right) \right)^2 \left(\int_0^{T_{\mathrm{s}}} \sigma_{mn}(\delta) d\delta \right)^2} \right)} \right) \tag{74}$$

It assumes that each user transmits M data bits and D are the overall transmission duration that is from transmission beginning of the first user to transmission end of the last user. Hence, the overall throughout can be expressed as [2]

$$T_{\mathrm{sum}}(\boldsymbol{p}) = \frac{1}{D} \sum_{n=1}^{N} M\left(1 - P_{\mathrm{b},n}(\boldsymbol{p})\right), \tag{75}$$

where

$$\boldsymbol{p} = \left[p_{1,\mathrm{tx}} \quad p_{2,\mathrm{tx}} \quad \cdots \quad p_{N,\mathrm{tx}} \right]^{\mathrm{T}}. \tag{76}$$

After Optimal Power Allocation, the optimal power vector $\boldsymbol{p}_{\mathrm{opt}}$ shall be achieved.

$$\begin{aligned} \boldsymbol{p}_{\mathrm{opt}} &= \arg\max_{\boldsymbol{p}} \left(T_{\mathrm{sum}}(\boldsymbol{p}) \right) \\ &= \arg\max_{\boldsymbol{p}} \left(\sum_{n=1}^{N} \left(1 - P_{\mathrm{b},n}(\boldsymbol{p})\right) \right). \end{aligned} \tag{77}$$

The procedure of finding $\boldsymbol{p}_{\mathrm{opt}}$ is introduced as follows:

A. Determine the Minimum Transmission Power of Each User

The transmission power of each user shall be larger than a minimum value to guaranty its own link quality. It assumes that the minimal SINR of the n-th user is γn,min (dB) according to its different service type. We set the unit power interference $\underline{I}^{\mathrm{u}}_{mn}$ as

$$\underline{I}^{\mathrm{u}}_{mn} = \frac{\underline{I}_{mn}}{p_{m,\mathrm{tx}}} = \frac{1}{T_{\mathrm{s}}^2} \left(\sum_{l=1}^{M} \left(h^*_{l,n} h_{l,m} \right) \right)^2 \left(\int_0^{T_{\mathrm{s}}} \sigma_{mn}(\delta) d\delta \right)^2. \tag{78}$$

$$n = 1, 2, ..., N, m = 1, 2, ..., N, m \neq n$$

It has

$$\frac{p_{n,\mathrm{tx}} N_s^2 \left(\sum_{l=1}^{M} |h_{l,n}|^2 \right)}{N_s N_0 + \sum_{m=1, m\neq n}^{N} p_{m,\mathrm{tx}} \underline{I}_{mn}^{\mathrm{u}}} \geq 10^{\frac{\gamma_{n,\min}}{10}}, n = 1, 2, ..., N. \quad (79)$$

Then it can be rewritten as

$$\boldsymbol{Gp} \geq \boldsymbol{n}' \quad (80)$$

where

$$\boldsymbol{G} = \begin{bmatrix} N_s^2 \left(\sum_{l=1}^{M} |h_{l,1}|^2 \right) & -10^{\frac{\gamma_{1,\min}}{10}} \underline{I}_{21}^{\mathrm{u}} & \cdots & -10^{\frac{\gamma_{1,\min}}{10}} \underline{I}_{N1}^{\mathrm{u}} \\ -10^{\frac{\gamma_{2,\min}}{10}} \underline{I}_{12}^{\mathrm{u}} & N_s^2 \left(\sum_{l=1}^{M} |h_{l,2}|^2 \right) & \cdots & -10^{\frac{\gamma_{2,\min}}{10}} \underline{I}_{N2}^{\mathrm{u}} \\ \vdots & \vdots & \ddots & \vdots \\ -10^{\frac{\gamma_{N,\min}}{10}} \underline{I}_{1N}^{\mathrm{u}} & -10^{\frac{\gamma_{N,\min}}{10}} \underline{I}_{2N}^{\mathrm{u}} & \cdots & N_s^2 \left(\sum_{l=1}^{M} |h_{l,N}|^2 \right) \end{bmatrix}$$

$$\boldsymbol{n}' = \begin{bmatrix} 10^{\frac{\gamma_{1,\min}}{10}} N_s N_0 & 10^{\frac{\gamma_{2,\min}}{10}} N_s N_0 & \cdots & 10^{\frac{\gamma_{N,\min}}{10}} N_s N_0 \end{bmatrix}^{\mathrm{T}} \quad (81)$$

$\boldsymbol{G}$ is a positive definite matrix if $\underline{I}_{mn}^{\mathrm{u}}$ is smaller enough than N_s^2. Then

$$\boldsymbol{p} \geq \boldsymbol{p}_{\min} = \boldsymbol{G}^{-1}\boldsymbol{n}' \quad (82)$$

B. Find the Optimum Transmission Power of Each User Iteratively

The maximum transmission power of each user is pmax, which adheres to the Federal Communications Commission (FCC) requirement [4]. Our task is to find the optimum power vector from, which is a nonlinear optimization problem. Computation of the gradient function and Hessen Matrix of Tsum(p) has a extremely high complexity with the increase of number of users N. Therefore, we introduce an iterative algorithm used to find a local maximum value of Tsum(p). The pseudo code of the algorithm can be expressed as:

$p_{n,ini} = p_{max}$, n =1,2,…,N;

$p_n = [p_{n,min}, p_{max}, C]$, n =1,2,…, N; //power candidate vector. C: number of elements

***for** cnt_L = 1 to Number of Loops*

$T_{cnt\_n,cnt\_p}=0$;

***for** cnt_n = 1 to N*

***for** cnt_p =1:C*

$T_{cnt\_n,cnt\_p} = T_{sum}\{ p_{cnt\_n}(cnt\_p), (p_{n,ini}, n\neq cnt\_n)\}$;

end

$p_{cnt\_n,ini} = \mathrm{argmax}(T_{cnt\_n,cnt\_p})$;

end

end

C. Computional Complexity of Optimal Power Allocation (OPA)

The computational complexity of OPA is

$$O(OPA) = N_{\mathrm{loops}} NC, \quad (83)$$

where Nloops is the number of loops, N is the number of active users and C is the length of the candidate power vector.

VI. SIMULATION RESULTS

The performance of 22-finger rake receiver and Successive ML receiver (SML) are depicted in Figure 3.

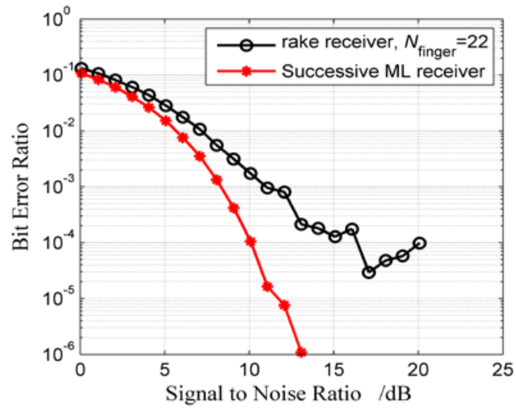

Fig. 3 22-finger rake receiver V.S successive ML receiver

For simplicity, only single user scenario is investigated since MUIs from interferers are considered as AWGN. As can be seen from Figure 3, SML can achieve much lower BER than rake receiver in high SNR case.

The performance of different channel estimation methods are depicted in Figure 4. Under the assumption of uncorrelated Gaussian noise, Maximum Likelihood (ML) estimator and Least Squares (LS) estimator show identical performances, which are closed to the perfect channel estimator. Bind channel estimator shows the worst performance in comparison to other approaches.

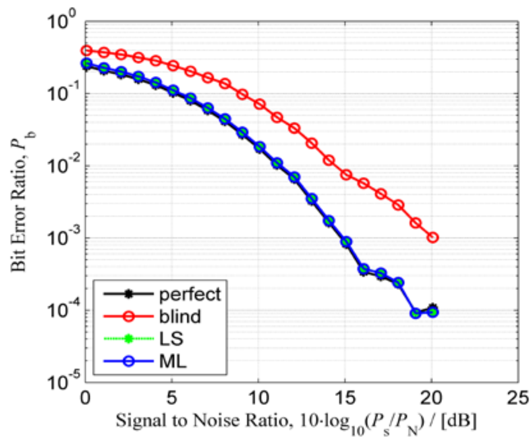

Fig. 4 Rake receiver with different channel estimation

Figure 5 shows the overall throughput with increase of number of active users using multi user rake receiver. It is obvious that OPA outperforms MPA with the increase of number of active users.

VI. CONCLUSION

In this research, we design a kind of Successive Maximum

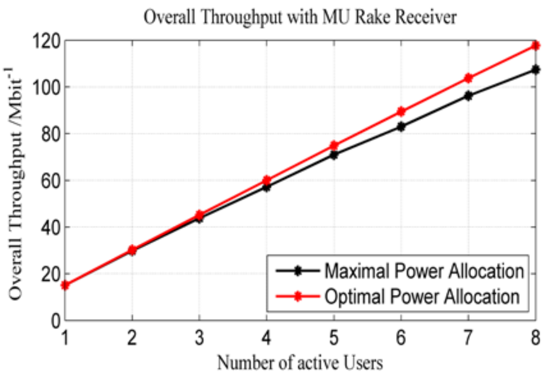

Fig. 5 Overall throughput with different number of active users

Likelihood (SML) receiver shows better performance than rake receiver. To evaluate the performance of two kinds of receivers, several novel channel estimators are designed. Under the assumption of uncorrelated Gaussian noise, ML channel estimator outperforms blind channel estimation. Meanwhile, we establish a centralized UWB network, which uses the novel Optimal Power Allocation (OPA) mechanism with the low computational complexity to achieve larger network throughput than Maximum Power Allocation (MPA) under the multi user scenario.

REFERENCES

[1] M. Benedetto, G. Giancola: "Understanding Ultra Wide Band Radio Fundamentals". Prentice Hall Communications Engineering and Emerging Technologies Series, 2004.

[2] D. Tse, P. Viswanath: "Fundamentals of Wireless Communication". Cambridge University Press, 2005.

[3] G. Giancola, C. Martello: "Radio resource management in infrastructure-based and ad hoc UWB networks". Wireless Communication and Mobile Computing, 2005.

[4] IEEE Standard - "Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (WPANs)", IEEE Std 802.15.4a -2007.

[5] M. Lad: "Ultra-Wideband: The Next Generation Personal Area Network Technology".

[6] A. F. Molisch: "Introduction to UWB Signals and Systems", August 25, 2006.

[7] Z. Wang and X. Yang, "Blind Channel Estimation for Ultra Wide Band Communications Employing Pulse Position Modulation", IEEE Signal Processing letters, vol. 12, no. 7, July 2005.

[8] J.G. Proakis, "Digital Communications", 3rd Edition, New York: McGrau-Hill International Editions, 1995.

[9] A. F. Molisch, "Status of Models for UWB Propagation Channels", IEEE Transactions on Wireless Communications, 2006.

[10] A. Saleh and R. Valenzuela, "A statistical model for indoor multipath propagation", IEEE Journal on Select. Areas Commun., vol. SAC-5, no.2, pp. 128 – 137, Feb. 1987.

[11] M.G. Khan, et al, "Performance Evaluation of RAKE Receiver for UWB Systems using Measured Channels in Industrial Environments", International Conference on Wireless Broadband and Ultrawideband Systems, Sweden, 2006.

[12] D. Cassilolli, M. Z. Win, F. Vatalaro, A. F. Molisch, "Performance of Low Complexity Rake Reception in a Realistic UWB Channel", Proc. IEEE ICC'03, vol. 2, pp. 763767, 2003.

[13] C. Carbonelli, U. Mengali and U. Mitra, "Synchronization and Channel Estimation for UWB Signals", IEEE Global Telecommunications Conference, pp. 764-768, December 2003.

Shangbo Wang was born in China, on September 19, 1981. He received the B.Sc. degree from the China University of Mining and Technology (CUMT) in electronic and electrical engineering in 2003 and M.Sc. degree from the University of Duisburg Essen, Germany in 2007, respectively. From 2007 to 2011, he worked in the department of Kommunikationstechnik in the University of Duisburg Essen as a research member. During that time, he was involved in the development of Ultra Wide Band communication systems, position location techniques, tracking systems.

He is currently a research assistant in Siemens Cooperate Technology (Siemens CT). His research interests include statistical signal processing, Ultra Wide Band communication, Location and Tracking and QoS parameter optimization.

Jörg Hüttner was born in Hof, Germany, in 1980. He received the Dipl.-Ing. degree in electrical engineering and Dr.-Ing. (Ph.D.) degree from the University of Erlangen–Nuremberg, Erlangen, Germany, in 2005 and 2010, respectively. He was with the Wireless Sensors and RF Technology Group, Siemens Corporate Technology, Munich, Germany, as a Ph.D. Researcher. He has been involved in the system and circuit design of several radar and localization projects. He is currently working as a System Engineer with Corporate Technology, Siemens AG, Munich, Germany. His research interests include UWB radar and local positioning systems.

Andreas Waadt received the diploma (M.Sc. equiv.) in electrical engineering from the University of Duisburg, Germany, in 2004. Since 2004 he is in the department of Communication Technologies (KommunikationsTechnik) at the University of Duisburg. His areas of interest include signal processing, quality of service, and location and tracking in mobile networks.

Andreas Ziroff received the Dipl.-Ing. in electrical engineering from TU Darmstadt and, in cooperation with Siemens Corporate Technology worked towards his PhD which he received from University of Ulm in 2006. He is with Siemens AG and investigates Microwave Systems and Technologies and their technical valence for future applications in the Sectors of the Company. His research interests include System architectures for RF and Microwave systems as well as assembly and interconnect technologies for microwave frequencies.

Peter Jung received the diploma (M.Sc. equiv.) in physics from University of Kaiserslautern, Germany, in 1990, and the Dr.-Ing. (Ph.D.EE equiv.) and Dr.-Ing. habil. (D.Sc.EE equiv.), both in electrical engineering with focus on microelectronics and communications technology, from University of Kaiserslautern in 1993 and 1996, respectively. In 1996, he became private educator (equiv. to reader) at University of Kaiserslautern and in 1998 also at Technical University of Dresden, Germany. From March 1998 till May 2000 he was with Siemens AG, Bereich Halbleiter, now Infineon Technologies, as Director of Cellular Innovation and later Senior Director of Concept Engineering Wireless Baseband. In June 2000, he became Chaired Professor for Communication Technologies (KommunikationsTechnik) at the Gerhard-Mercator-University Duisburg. In 1995, he was co-recipient of the best paper award at the ITG-Fachtagung Mobile Kommunikation, Ulm, Germany, and in 1997, he was co-recipient of the Johann-Philipp-Reis-Award for his work on multicarrier CDMA mobile radio systems. Professor Jung served as chairman of the Fakultätentag für Elektrotechnik und Informationstechnik (FTEI) e.V., and member of the board of VDE/VDI-GMM. He was a member of the editorial board of IEEE Transactions on Wireless Communications and has been a member of the editorial boards of the Springer Journal of Wireless Personal Communications and of the Hindawi Research Letters in Communications. His areas of interest include wireless communication technology, software defined radio, and system-on-a-chip integration of communication systems.